DOCUMENT RESUME

ED 370 760 SE 053 047

AUTHOR Guskey, Thomas R.; Passaro, Perry D.
TITLE How Mastery Learning Can Address Our Nation's Science Education Needs.
PUB DATE 92
NOTE 35p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, 1992).
PUB TYPE Reports - Descriptive (141) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Curriculum Development; Discovery Learning; Elementary Secondary Education; High Schools; *Mastery Learning; *Mastery Tests; Minimum Competencies; Minimum Competency Testing; Science Curriculum; *Science Education; Science Process Skills; Skills; Teacher Guidance
IDENTIFIERS Missouri

ABSTRACT

Mastery learning can combine the strengths of direct instruction with the strengths of discovery learning. This paper describes how mastery learning is being used in Missouri schools to enhance the quality of instruction in science at all grade levels. In addition, the dramatic results in student science achievement that have occurred within the state since this program's inception are discussed. Missouri educators developed a list of science competencies all students should attain prior to completion of their secondary education. The Missouri Mastery Achievement Tests were developed using the principles that: (1) competencies should not be restricted to the easiest to assess; and (2) competencies and skills should be mainly higher order outcomes. (PR)

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HOW MASTERY LEARNING CAN ADDRESS OUR NATION'S SCIENCE EDUCATION NEEDS

Thomas R. Guskey, University of Kentucky

Perry D. Passaro, Utah State University

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Paper presented at the 1992 Annual Meeting of the
American Educational Research Association
San Francisco, California

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Abstract

Policy makers and the American public are demanding better science education for all children growing up in a technologically advanced society (National Science Testing Board, 1983). The majority of science educators agree that such improvements can be accomplished only through a program that addresses both science fundamentals and higher order cognitive skills. Therefore, a comprehensive, broad-based program is necessary if children are to be prepared to enter a global community that is increasingly scientifically dependent (National Science Testing Board, 1983; Sachse, 1990). Science educators do not agree, however, on how to attain these ambitious goals. Some argue for methods that provide "direct instruction" to students while others believe that only through instructional procedures that utilize "discovery learning" will we be able to reach our science education aims.

There is however, an instructional process that makes the choice between direct instruction and discovery learning unnecessary. This process combines the strengths of both approaches and is consistent with current cognitive psychological theory regarding the process of learning science. This process is generally refered to as mastery learning.

This paper describes how mastery learning is being used in Missouri schools to enhance the quality of instruction in science at all grade levels. In addition the dramatic results in student science achievement that have occurred within the state since this programs inception, are discussed.

Numerous recent reports have described the poor performance of our nation's school children in the area of science (National Commission on Excellence in Education, 1983; National Science Education Board, 1983; Carnegie Task Force on Teaching as a Profession, 1986; Mullis, Jenkins, & Lynn, 1988; Raizen, 1989; Rutherford, 1989). These reports indicate that, for the most part, there has been a steady decline in science achievement scores in the U.S. over the last two decades (National Assessment of Educational Progress, 1979; Ashworth, 1990).

Policy makers and the American public are demanding better science education for <u>all</u> children who are growing up today in a technologically advanced society (National Commission on Excellence in Education, 1983; National Science Education Board, 1983). They are also demanding this ambitious and worthy aim be addressed quickly, without large funding increases, and with strategies based upon carefully validated instructional practices to ensure student success. Furthermore, there are two well defined national goals which have been communicated by numerous science education experts. The first of these goals is that every American child have a through understanding of fundamental scientific principles and processes (National Commission on Excellence in Education, 1983; National Science Education Board, 1983). The second goal is that students have abundant opportunity to design and conduct real experiments and to carry their thinking beyond the information given. In other words, it is seen as essential that students be provided with opportunities to participate in the same types of higher order cognitive process that are critical to the methods of science (National Science Education Board, 1983; Mullis, et. al., 1988; Rutherford, 1989; Ashworth, 1990). The majority of science educators now believe, that only through a program that emphases science fundamentals and higher order scientific

thinking, will our nation's children be prepared to enter a global community which becomes more scientifically dependent and complex every day (Sachse, 1990).

These recommendations for change in science education programs are guided in large part by current findings in cognitive psychology (Resnick, 1983; Linn, 1986; Carey, 1986). This research shows that students come to science classrooms with numerous "misconceptions" about how scientific processes operate (Clement, 1982; McCloskey, 1983; McDermott, 1984). Such misconceptions are viewed by cognitive psychologists as naive approaches to problem solving that are perceptually appealing but inconsistent with scientific evidence. According to the theories of (Piaget, 1929) childrens' cognitive abilities develop from a precausual stage where the child's understanding of the world is incomplete, to a causual stage where the child accurately understands the world.

One of the first studies of misconceptions was performed by Cole and Raven (1969), who determined that misconceptions of density and specific gravity exist in children, adolescents, and adults. Although current research in this area focuses primarily on the physical sciences (Clement, 1982; McCloskey, 1983; McDermott, 1984), Carey (1986) reports misconceptions in other sciences and at all age and grade levels.

Why should these misconceptions occur? Ausubel, Novak, & Hanesian (1978) suggest that students come to a new area of study with their own conceptions or misconceptions about how a process operates. Furthermore, these misconceptions may be in direct conflict with the empirically-derived principles of the

discipline. In such cases, learning becomes a process in which new concepts must displace or be remolded from stable concepts that the student has constructed over many years (Clement, 1982). Research conducted by Passaro, Cole and Wala (1989) has demonstrated that these misconceptions are difficult to remediate and seemingly unaffected by traditional methods of classroom instruction.

In part because of difficulties in remediating misconceptions, science educators are in a disagreement with regard to the best methods to teach science. This controversy is between "direct instruction" and "discovery learning" approaches to science education. Direct instruction refers to the explicit presentation of facts and processes in science, and discovery learning refers to the presentation of opportunities for learners to discover important scientific principles by interacting with scientific material (Linn, 1986).

An educational process is available, however, that meets our countries science education needs and addresses the difficulties identified in remediating scientific misconceptions. This process also encompasses the strengths of both direct instruction and discovery learning approaches. It is known as mastery learning.

MASTERY LEARNING THEORY, COGNITIVE SCIENCE AND SCIENCE EDUCATION

In the middle 1960's Benjamin S. Bloom began a series of investigations on how the most powerful aspects of tutoring and individualized instruction might be adapted to improve student learning in group-based classrooms. He noted that

while different students learn at different rates, all could learn well if provided with the necessary time and appropriate learning conditions. In fact, Bloom indicated that under these more appropriate learning conditions, 80% or more of all children could reach a level of achievement typically attained by only the top 20% under more traditional forms of instruction (Bloom, 1968).

To provide these more appropriate learning conditions, Bloom (1971) recommended that the material to be learned first be divided into instructional units, similar to the way the chapters are organized in a course textbook. Following a teacher's initial instruction over the material in each unit a formative evaluation or quiz is administered to students, not as part of the grading process but, instead, to provide feedback to both students and the teacher about what material was learned well and what was not. Special "corrective" activities are then offered to students who require additional time and practice to learn the material. Following the corrective work a second formative evaluation is administered to check on the success of the correctives and to offer students a second chance to achieve success. For those who have learned the material well, special enrichment activities are planned to give them opportunities to strengthen and broaden their learning. Both the inital instruction and the enrichment activities allow students the opportunity to expand their learning so that they may apply scientific information and concepts in rewarding, challenging and creative ways. These types of opportunities are lacking in many science education programs, yet these experiences have been identified by science educators as necessary if the student is to learn how to apply science in their own lives (Bybee, 1989).

INSERT FIGURE 1. HERE

Typically, suggested corrective activities are made specific to each item or part of the test. In this way each student needs to work on only those concepts or skills which he or she has not yet mastered. In other words, the correctives are individualized. They are designed to present the material differently and involve the student in alternative learning activities, identifying for the student another, hopefully more appropriate approach to learning that concept. The corrections may be worked on with the teacher, with peers in cooperative learning teams, or by the student independently. It is through these corrective activities that students misconceptions may be identified and addressed. Here the teacher may interact with students and provide them with opportunities to repeat errors and then together, review the cognitive concepts that were relied on during manipulation of the problems. Through this individualization of instruction students' misconceptions can be identified and remediated before they are permitted to proceed to the next instructional unit where the misconception would become further compounded and more difficult to remediate.

Thus, with the results from this formative assessment each student has a very specific prescription of what more needs to be done to master the material or particular learning objectives from that unit, and the educator has had an opportunity to identify and remediate specific misconceptions from the students

scientific reasoning. Through this process of formative testing, combined with systematic correction of individual learning difficulties, including misconceptions, each student can be provided with a more appropriate quality of instruction than is possible under more traditional approaches to classroom teaching. Under these more appropriate conditions, Bloom believed that virtually all students could learn very well and truly master the subject material (Bloom, 1976).

Another way mastery learning helps teachers focus on the development of higher-order cognitive skills within each instructional unit is through the construction of a table of specifications. These tables are basically outlines of learning objectives for each unit of instruction. They also provide for the teacher a hierarchy of learning. The lowest levels of this hierarchy represent the simplest kinds of learning, while the higher levels represent more advanced cognitive skills (Bloom, Englehart, Furst, Hill & Krathwohl, 1956; Bloom, Hastings, & Madaus, 1971). Generally, teachers who utilize this table of specifications develop instructional objectives which are of higher level on the cognitive hierarchy and thus, improve the quality of their students science instruction.

INSERT FIGURE 2. HERE

Mastery learning, therefore, encompasses the strengths of direct instruction approaches to science education through formative evaluations and

correctives. It also utilizes the strengths of discovery learning in both the inital instruction and enrichment activities. This merger of direct instruction and discovery learning is congruent with psychological research on learning scientific principles which shows that discovery methods work best when factual information from the discipline is already mastered by the student (Newell & Simon, 1972; Larkin, McDermott, & Simon, 1980; Chi, Glasser, & Reeves, 1986; Perkins & Salomon, 1989).

Since the development of the ideas of mastery learning, programs incorporating these strategies have been initiated in school systems across the United States. These programs have typically resulted in impressive gains in student learning. Meta-analyse[1] on the effects of mastery learning report average effect sizes of nearly one standard deviation (Block & Burns, 1976; Kulik, & Kulik, 1986; Guskey & Pigott, 1988; Walberg, 1990; Kulik, Kulik, & Bangert-Downs, 1990).

Other positive effects of mastery learning include students' higher level cognitive skills. Research conducted by Mevarech (1980) on higher order cognitive skills, particularly the ability to apply, analyze, and synthesize information has demonstrated that 40-60% of mastery learning students (depending upon various types of corrective strategies used) attained mastery (80 percent correct) on assessments of higher level cognitive skills. However, only 12% of the students taught with conventional instructional methods attained mastery of these higher order skills.

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[1] Meta-analysis is a statistical technique that describes the results of tests of similar hypotheses across many studies.

Explanations for these findings can be offered by psychological theories on knowledge representation and problem solving strategies. Knowledge representation theories state that learning is a process of construction. If a student is to understand a new piece of information she must relate it to a mentally represented structure, in other words, integrate it with already existing knowledge. This in turn, provides a framework for comprehension (Carey, 1986). Within a mastery learning framework the clearly defined structure of the instructional unit, its consistency with preceding instructional objectives, and the teacher's utilization of the table of specifications helps students construct a cognitive hierarchy that is typically richer and more elaborate than that offered in most curricula.

Problem solving strategies have been approached from two perspectives. The first states that problem solving involves general strategies that are not specific to a discipline. The second perspective states that problem solving is content bound and unaffected by general heuristics. Research conducted by Perkins and Salomon (1989) supports both positions. They state that problem solving does entail a large knowledge base. This alone, however, is not sufficient. When faced with new unfamiliar problems, general heuristics must be used.

In the corrective activities utilized in mastery learning students are provided with opportunities to find the correct answer, and also identify why a particular response is correct or incorrect. Furthermore, corrective actives encourage students to engage in strategies that increase their ability solve problems. Within the enrichment activities students are provided with further opportunities to apply the knowledge they have gained from the instructional

unit, including solving additional challenging problems of the students choice.

The Missouri Statewide Comprehensive Project for Improving Science Achievement

Since 1980 Missouri educators have been engaged in a comprehensive and systematic effort to improve the quality of science education in their schools. The State Department of Education determined that the ideas and techniques of mastery learning and cooperative learning were relevant additions to the state's science education program [2]. As previously stated mastery learning theorizes that all students can learn what we teach to a satisfactory level if classroom instruction is encouraged to provide students with adequate time and appropriate learning conditions (Carroll, 1963; Bloom, 1968; Guskey, 1985; Block, Efthim & Burns, 1989). Cooperative learning provides students with opportunities to incorporate socialization into the learning process and de-emphasizes individualistic or competitive learning situations (Johnson & Johnson, 1987). Cooperative learning processes have also been identified as a technique that helps to facilitate students sharing of ideas about science and technology (Sachse, 1990). Furthermore, cooperative projects simulate the actual processes used by scientists in their research efforts (Watson, 1968).

The State Department of Education began its efforts by familiarizing Missouri science educators with mastery learning and cooperative education concepts, and then soliciting their input on how best to implement programs based upon these premises. Based on this input a series of one-day conferences were

[2] A detailed description of the Missouri Statewide improvement program can be found in Baker, King, & Wulf, (1989).

conducted around the state. Shortly thereafter, the Missouri State Legislature passed an Excellence in Education Act, a comprehensive bill that greatly extended the implementation of mastery learning and cooperative education programs throughout the State. Specifically, the act required the Department of Education to identify "core competencies and key skills" in the sciences as well as other academic areas that all Missouri students would be expected to learn. In addition, the Act required the Department of Education to insure that a statewide testing system be developed to assess students' mastery of these competencies and skills. The results from this annual testing were to be reported to the State General Assembly.

Development of the Missouri Mastery Achievement Tests

One of the first steps taken in implementing the Missouri excellence in education act was the formation of a statewide committee to identify the science competencies and key skills that all students would be expected to attain prior to completion of their secondary education. This committee was composed of science educators from elementary, secondary and post-secondary levels, subject area specialists, and school administrators. The committee then moved downward through the grades, seeking to identify the related competencies and skills necessary for success in each preceding grade.

Two principles guided the committee's work. One was the decision made early in the development process that the competencies and skills identified should not be restricted to those that are easiest to assess through paper and pencil testing insturments. Committee members believed that the importance of learning

outcomes should take precedence over the means used to certify its attainment. The second principle, related to the first, was that the identified competencies and skills should be mainly higher order outcomes rather than low level ones based on simple recall of factual information. Although such outcomes are typically harder to teach and more difficult to assess, they are also more important to the development of scientific thinking.

After extensive review and revision, a preliminary version of proposed competencies and skills were developed. This version was distributed to science educators in every school district and served as the main topic of a series of regional conferences sponsored by the State Department of Education in the Fall of 1985. The teachers and administrators who participated in these conferences aided in the refinement of the competencies and skills.

This work cumulated in the publication of the Missouri Core Competencies and Key Skills in 1986. This publication emphasized that these competencies and skills were to serve as a "curriculum skeleton". They did not represent, and should not be considered a complete curriculum. They were instead the learning outcomes that all children should master. It remained the responsibility of Missouri educators at the district, building and classroom levels to determine what the "body" of the skeleton should look like. Thus while the curriculum "bodies" fashioned by different teachers might look quite different, their skeletons, would be much the same.

To assess the students mastery of the selected core competencies and key skills, Department of Education staff members met with representatives of several

major commercial testing companies. But after detailed consideration of each proposal, it was determined that none truly met Missouri's needs. Few of the test items shown to Department staff tapped skills other than simple recall, especially in science. Tests composed of such items were determined to be a poor match to the outcomes identified as most important. Therefore, the decision was made to develop the tests within the state using those who have firsthand knowledge of the states children, Missouri's teachers and administrators. Groups of educators developed test items and alternate groups reviewed these items for quality and content agreement with the identified skills and competencies. In addition, the Department of Education utilized 20 nationally recognized testing experts on the topics of test construction, and congruence with learning outcomes. Before their completion the tests were also reviewed by outside experts for readability, and other issues that could contribute to testing bias. Tests were developed for grades 3 through 10 and then field tested in two rounds before reaching their final form. Figures 3 to 6 provide examples of selected science items from the MMAT for grades 3, 6, 8, and 10.

INSERT FIGURES 3,4,5,AND 6 HERE

Results

In 1987, 1988, and 1989 randomly selected samples of 5000 Missouri students were assessed with the MMAT, and nationally standardized achievement tests--portions of the Iowa Tests of Basic Skills (ITBS) for grades 2-8 and the Test of Achievement and Proficiency (TAP) for grades 9 and 10. Statewide, from 1987 to 1988, "educationally, and statistically significant" gains had been realized in science performance as measured by the MMAT (Missouri State Department of Elementary and Secondary Education, 1989). A yearly scale score gain of 11 points is considered "educationally significant" by the State Department of Education; gains of 6-7 points are probably "statistically significant", given the less than 3 point MMAT sampling error.

INSERT FIGURE 7 HERE

Figures 8 and 9 display "typical"[3] Missouri students' performance on the ITBS/TAP for the 1987 baseline, 1988, and for 1989. Missouri students generally made consistent year to year achievement gains in science. These data directly address the concerns of many educators about this project's impact upon educational excellence and student learning in science. Given these data, the

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[3] "Typical" is defined here as the percentile rank of median students on the ITBS for grades 3, 6, and 8, and on the TAP for grade 10.

project is having a positive effect on student achievement, whether that achievement is evaluated in terms of local or national standards.

INSERT FIGURES 8 & 9 HERE

These data do not address, however, many educators' concerns about the equality of student success in science education. These educators had stated that all children growing up in a technologically advanced society receive better science education (Sachse, 1990). In other words, these educators hoped to raise not only the average levels of student achievement statewide, but also the number of students performing at or above these high levels, regardless of the students' background.

The 1987 MMAT results were used to establish the initial baseline scale scores and to set baseline quintiles[4]. Figures 10-13 provide a comparison of the 1987 baseline data to the 1988 and 1989 test results. These data demonstrate that by 1988 a smaller percentage (about 2-5% less) of students were scoring in the lower quintiles and a larger percentage (about 2-15%) of students had moved to the highest two quintiles. By 1989 approximately 10% fewer students were in the bottom quintiles and 10-25% more had moved to the top quintiles.

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[4] These quintiles are scores which divide the distribution of scores into 5 groups, each containing one-fifth of the students. Numbers 1 through 5 designate the lowest to the highest quintiles, respectively.

INSERT FIGURES 10-13 HERE

Conclusion

Given the poor performance reported about our nations school children in the area of science education. Missouri's leadership, collaboration, cooperation and shared decision making has demonstrated that our nations' science education goals can be achieved. Even our nations' lofty aim of assuring that we teach and assess cognitive tasks that call for comprehension, application, or analysis and synthesis. To assure these aims were adequately addressed Missouri educators constructed the MMAT to so that about half of its items test higher level cognitive skills (Guskey & Block, 1990). Furthermore, Missouri has developed a science education program that is permitting all its children to succeed not only those identified as "scientifically gifted". Without such a comprehensive and penetrating program our nations' science education goals would remain just that, goals. Fortunately, we have a model which has demonstrated it ability to bring these goals into reality. This is accomplished through the integration of a science curriculum that includes current research or the process of how students learn science, with an instructional method that systematizes instruction into a procedure which is manageable by a classroom teacher.

Science today, more than ever before, is confronted with problems that will

require the concentrated efforts of experts from multiple disciplines years of focused study to arrive at an understanding and/or solution. Given the immense difficulties we are leaving for our children we must assure that they have the skills necessary to confront these problems.

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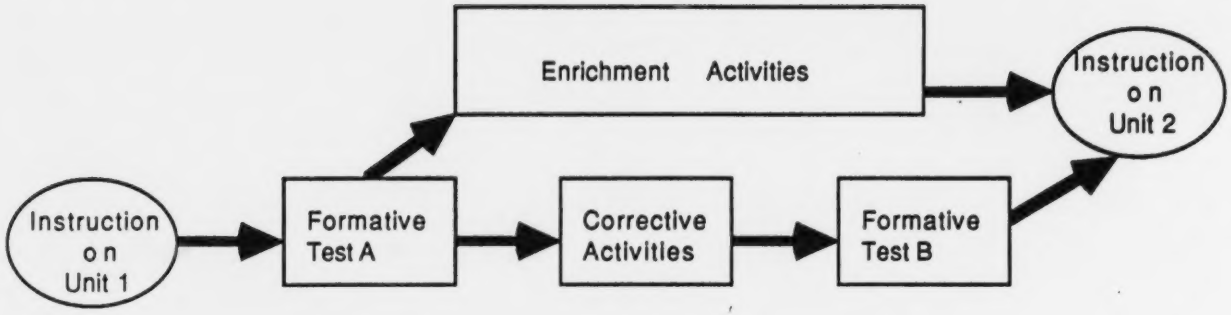


Figure 1. The process of instruction under mastery learning

Table of Specifications						
Knowledge of				Translations	Applications	Analyses & Syntheses
Terms	Facts	Rules & Principles	Processes & Procedures			

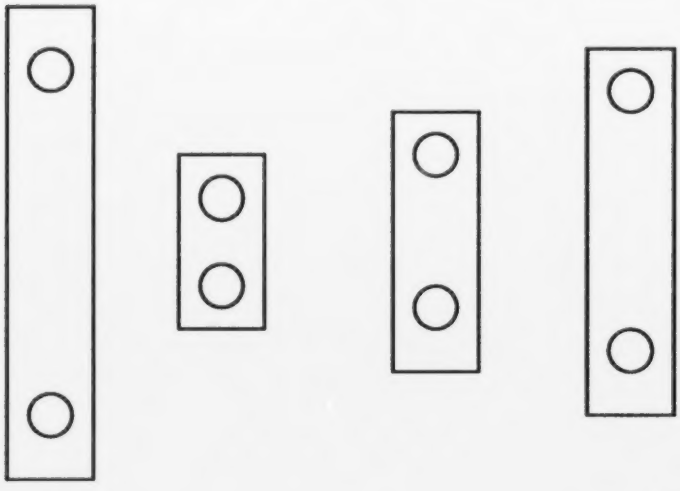
Figure 2. General outline for a table of specifications

Predict the effect on pitch when the source of the vibration is systematiclly altered

Lowest pitch when tapped with a spoon

Highest pitch when tapped with a spoon

Which metal strip would give a pitch between the lowest and highest pitch when tapped with a spoon?



A B C D

Figure 3. Sample MMAT science test item for grade 3

Classify examples of changes in matter as physical or chemical

Which is a chemical change?

A. ice melting

B. water evaporating

C. paper tearing

D. Cardboard burning

Figure 4. Sample MMAT science test item for grade 6

Identify the number of protons, neutrons and electrons of a common element using the periodic table and other information

IIIA	IVA	VA	VIA	VIIA	O
				1 H	2 He
5 B	6 C	7 N	8 O	9 F	10 Ne
13 Al	14 Si	15 P	16 S	17 Cl	18 Ar

The element fluorine has an atomic number of 9 and an atomic mass of 19. What is the number of neutrons in a fluorine nucleus?

A. 1

B. 9

C. 10

D. 19

Figure 5. Sample MMAT science test item for grade 8

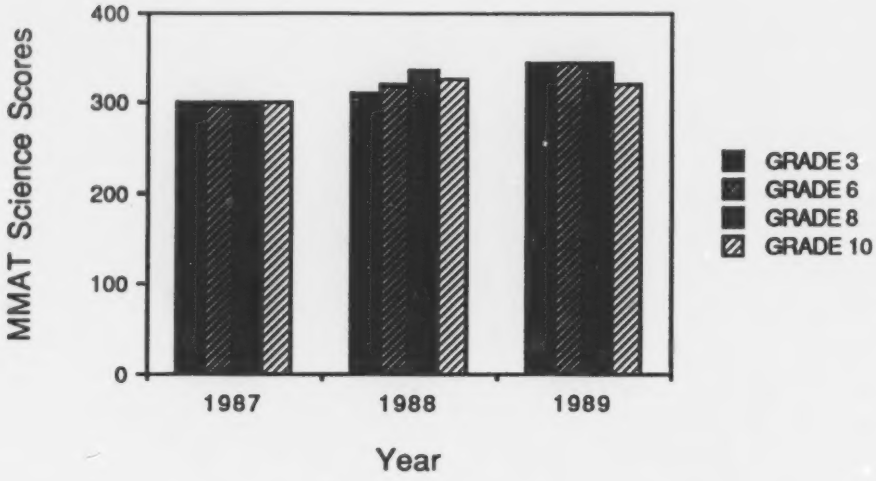


Figure 7. Mean Missouri MMAT science scores by year and grade level

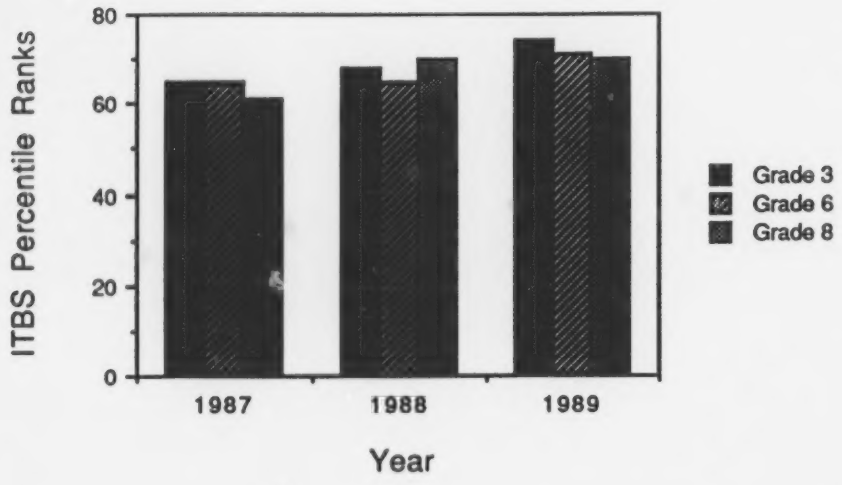


Figure 8. Median ITBS science percentile ranks by year and grade level

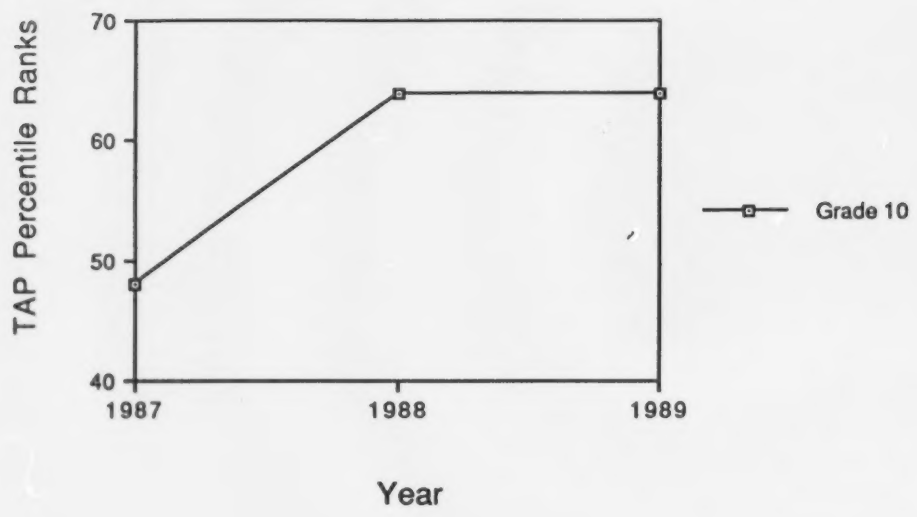


Figure 9. Median TAP science percentile ranks by year for grade 10

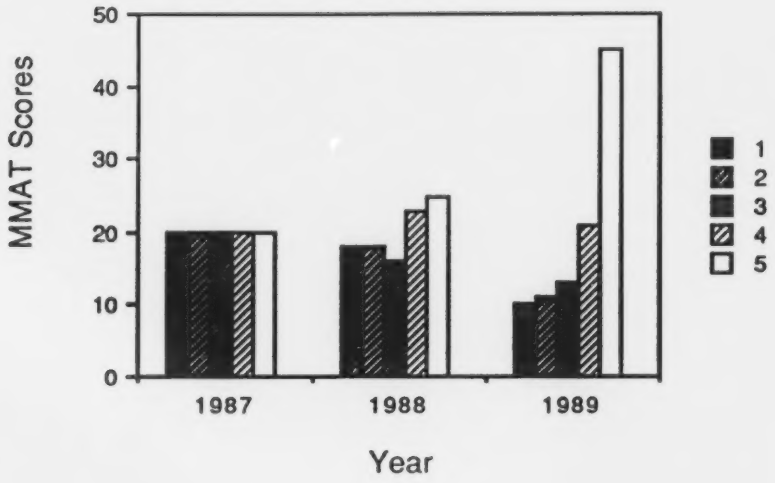


Figure 10. Statewide quintile distribution of MMAT scaled science scores for grade 3

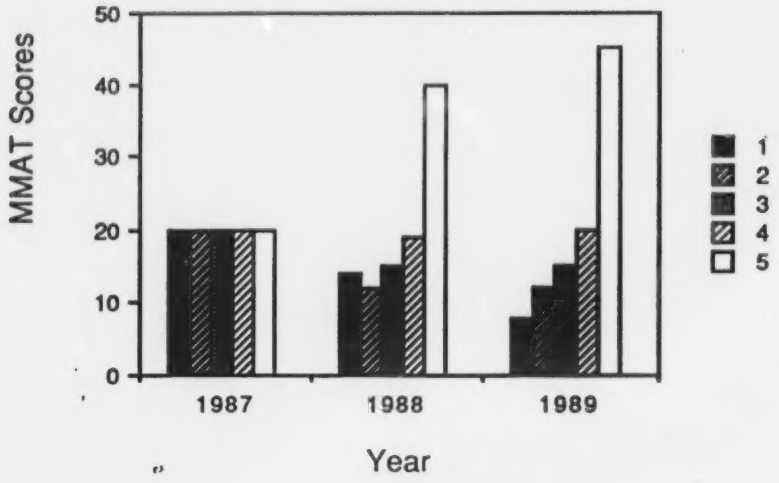


Figure 11. Statewide quintile distribution of MMAT scaled science scores for grade 6

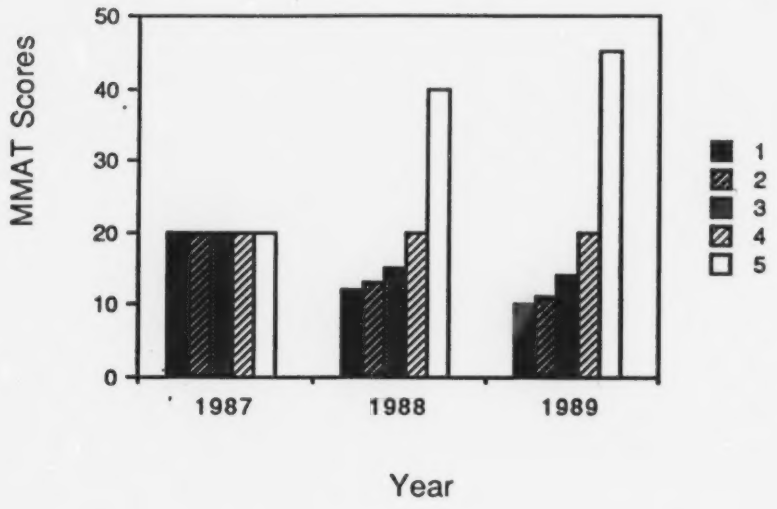


Figure 12. Statewide quintile distribution of MMAT scaled science scores for grade 8

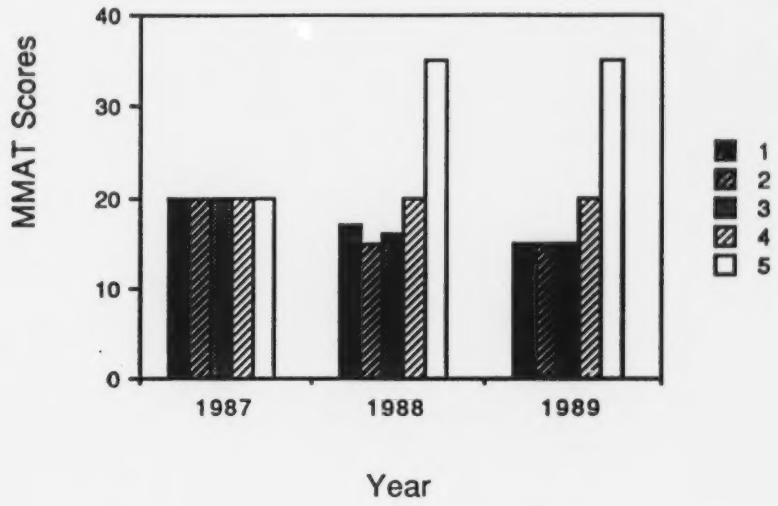
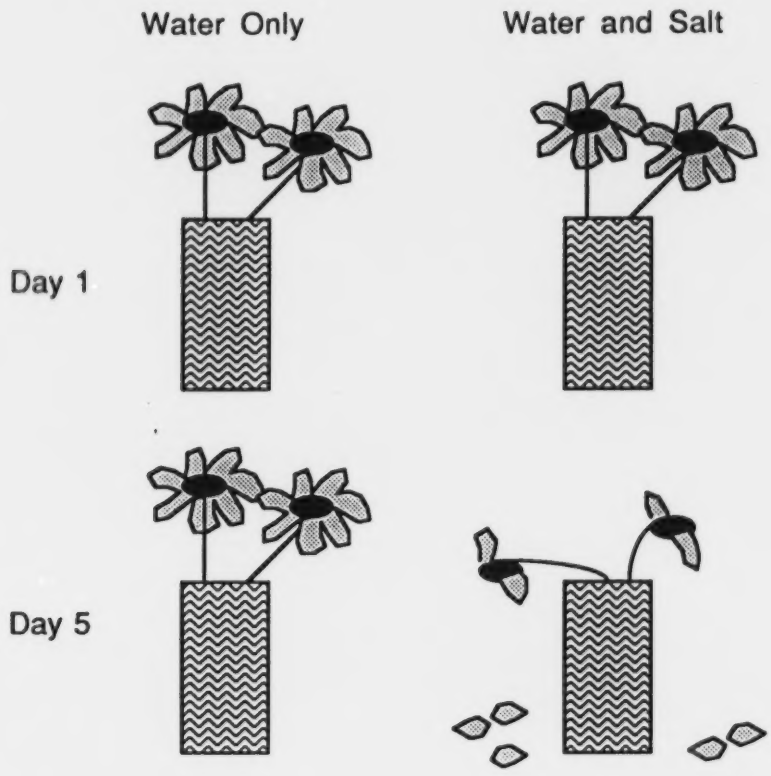


Figure 13. Statewide quintile distribution of MMAT scaled science scores for grade 10

Use the illustration to answer the next question.



The illustration above shows the results of an experiment to find out if adding salt to water help keep cut flowers fresh longer than plain water alone.

Why were flowers placed in a vase with only water?

A. as a control

B. to add data

C. to support the hypothesis

D. as an independent variable

Figure 6. Sample MMAT science test item for grade 10